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Guest editorial

Relevant irrelevancies

It is not uncommon to be presented with slides embellished with yellow text on a white ground, or blue text on a black ground. Yes, even at conferences on visual perception! The inevitable consequence is that no one in the audience is in any position to read the slides. What holds for text eo ipso applies to data points and curves in graphs. *Even the author* often freely admits to have problems to make out what's on the slide. You not infrequently hear something like "… you probably can't see this, but …". Sounds familiar to you? I'm always struck by the oddity of it.

For the hardcore scientist such design matters are utterly irrelevant—perhaps with the exception of white lettering on a white ground. What counts is the scientific content, not its packaging. For the *scientist in perception* this should perhaps be different. Although the design choice may indeed be irrelevant from the perspective of science, I feel a 'moral' obligation here.

A less trivial, but even more common, and perhaps more interesting and instructive, example involves *scatterplots*. Although I pick on a single example, there are numerous equally interesting cases. One could write a book about them.

Scatterplots are extremely common. At least half of the publications in experimental psychology contain a scatterplot of some sort. Any statistics software package lets you produce such plots. Scatterplots are most useful when you have to compare two datasets that 'ideally should be the same'. A common example is the data from two observers on the same set of stimuli—for instance, estimates of some quantity like weight, or intensity. Notice that we're very much in the spirit of Ernst Heinrich Weber's or Gustav Theodor Fechner's paradigms here. If the observers were physical measuring instruments, their results should be virtually identical. In practice we find significant scatter, which becomes explicit by plotting the results (for the same stimuli) of observer A (say) against those of observer B. A fake, but very typical, result would appear as the data in figure 1.

Figure 1 is entirely representative of the generic output of our software packages, and the generic figures printed daily in scientific journals. Yet this representation is *a very ineffective one* for several reasons, some having to do with perception, others with more general issues. Of course, the design of the graph is again *irrelevant* to the hardcore scientist.

A general issue is that something like 'weight' or 'intensity' is a nonnegative numerical quantity when expressed in some type of units—for example, Newtons for weights under typical conditions of gravity. The statistically universal representation—no prior assumptions—would thus be on a logarithmic scale. This was intuited by the early statisticians (Jeffreys 1939, 1957), and proven by Edwin T Jaynes (1968) from Bayesian principles. Interestingly, this neatly fits the researches of Weber ("Weber's Law", 1834), and Fechner (the 'Psychophysical Function', 1860). Thus, a better representation is the scatterplot shown in figure 2.

The scatterplot in figure 2 is indeed more generally useful than the version shown in figure 1. Why is it still a *bad representation*? Because it violates basic insights from the science of perception. There are a number of problems here. Let me start with a trivial one—one that is still fairly generic, and would equally apply to scatterplots in the exact sciences. If you want to compare two entities, then you should present them in similar settings. Otherwise the perception of equality becomes harder, and might well become biased. But here we use *different scales* on the two axes of the graph. Although the value ranges are indeed equal, the scalings are distinct.

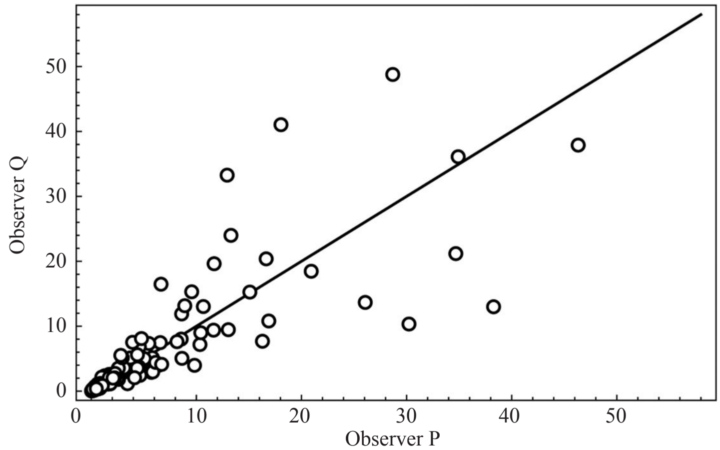

Figure 1. A generic scatterplot generated from fake data. The graph aspect ratio is 1 : 1.61803…, for the best of reasons. I know for sure—because I generated the data myself—that the results of two (virtual) observers differ only due to random, normally distributed errors. All values are nonnegative by their very nature (like 'intensity', it may be arbitrarily large or small, but it has to be *something*). These are all the data you're going to see in this editorial. You may just as well skip the other figures if you're a hardcore scientist—they merely repeat the same data. The discussion is on the *packaging*, not the *content*—that is, on the PERCEPTUAL CONTENT.

The reason for this is simple. Nobody cares, and the statistics packages prefer this particular aspect ratio. There are again reasons for *that*. One is that publishers usually try to avoid captions on the side, and prefer captions at the bottom. This saves wasted white space if the figure is in landscape, rather than portrait, format. Another reason is that some aspect ratios are supposed to be aesthetically attractive. In figures 1 and 2 the aspect ratio is the Golden Ratio (numerically, 1 : 1.61803…). If you like 'nice' numbers, then 2 : 3 (that is, 24 × 36 to photographers) may be preferable to you. But although 36 : 24 : 36 (Khamsi 2007) sounds better than 91.44 : 60.96 : 91.44, it is really the same—I'm just illustrating the irrelevancy of such numbers here. All that matters is the 'looks'. The Golden Ratio will do fine here.

Any aspect ratio different from unity is asymmetric in its representation of the two observers, and thus likely to misrepresent the data. This is another example of a *perceptually*

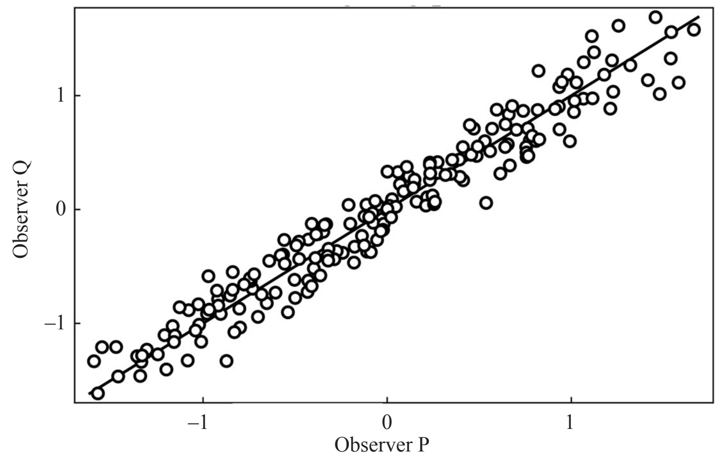

Figure 2. The same data as shown in figure 1, but plotted on doubly logarithmic scales. It is somewhat more convenient to judge the distribution of the scatter here. The key question is: are the two observers statistically the same? That is to say, are the data statistically invariant under permutation of the observers? This is not particularly easy to judge, at least in this plot.

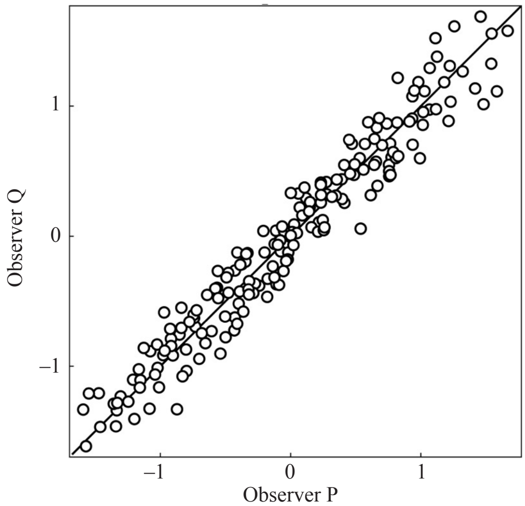

Figure 3. Again, we have the same data as shown in figure 1. In this plot the scalings of the axes have been made the same. Since the ranges are identical (also in figures 1 and 2, in case you failed to notice), we obtain a pleasant 'square' representation of the data. Equality of observers is formally identified by the straight line of unit slope. Are the observers indeed (statistically) equivalent? Here you have to judge (statistical) bilateral symmetry about the diagonal.

relevant irrelevancy. Applying basic insights from perception science leads to the much improved representation shown in figure 3.

Notice that figure 3 is indeed far *more effective* than either figure 2 or figure 1. It is fairly easy to judge the degree of equality here. Notice that exact equality is represented by the straight line of unit slope. Why is it, then, that such representations are rare in the literature? Even more surprising, why is it that even those in perception science are typically satisfied with a crummy representation like that in figure 2 (say)? They apparently simply follow the fashion imposed by the journal publishers, who decide on aspect ratio on vague historical grounds.

Notice that the two observers are treated on different footings in a representation like figure 2. If you prefer the aspect ratio for aesthetical, or historical reasons, then you should probably show *two plots*, say figure 2, for the same data with axes interchanged! Of course, nobody ever does this. No publisher would consent.

Rare examples of 'square' plots are those like figure 4, often adorned with much additional paraphernalia. Many statistics packages let you draw such plots, although they are, perhaps unfortunately, rarely used. They are usually—not always, but in the majority of cases—'square'. The reason why is obvious enough: it is much easier to compare the histograms of the coordinate values in a square plot. That this is indeed the case indicates (by implication) once again the doubtful nature of a representation like that in figure 2.

There are compelling reasons—from the perspective of the science of perception—why even the representation shown in figure 3 is perhaps not entirely satisfactory. The issue is that the task to judge equality is implemented as the perceptual task to judge bilateral symmetry about an axis that subtends a slope of 45º with the vertical (or horizontal—up to you). This is generally not a good idea, as Mach (1886) discovered. Bilateral symmetry is best detected about the vertical, worse so about the horizontal, and worst of all about an oblique axis. [For contemporary accounts see Barlow and Reeves (1979); Palmer (1985); Wagemans (1995, 1997).]

Mach (1886) speculated that it may be due to the bilateral symmetry of our bodies, including our brains. Thus bilateral symmetry about the vertical accounts for much of our preferences, in sexual mates, and so forth (Gangestad and Simpson 2000)! It is not different in science,

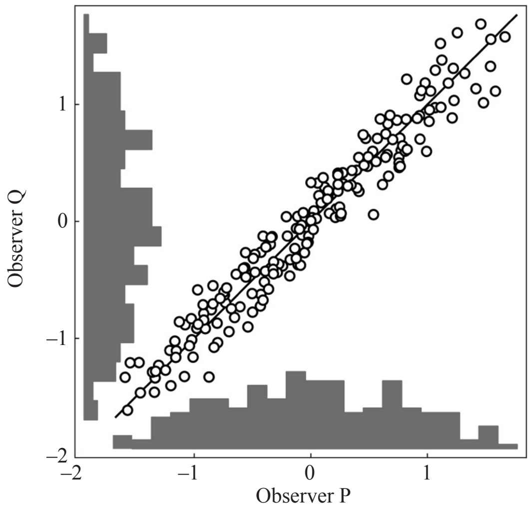

Figure 4. Again, we have the same data as shown in figure 1. In this plot the scalings of the axes have been made the same, as in the previous figure. Here the histograms of the individual responses are added, for one observer in the usual attitude, and for the other reflected about the diagonal. The histograms are neatly synchronized with the data points. This particular plot shows only the bare bones; many statistics packages let you come up with rather more impressive representations. Something to explore!

although we often like to pretend that we scientists are superminds that couldn't care less about mere embodiment. But you almost *have* to tilt your head in order to judge the symmetry. At least for me the urge is strong! Of course, you may—when nobody is watching—rotate the page by 45º, but then you are still perceptually biased by the frame of the page. Remember the square-diamond illusions (Pinna 2011)? A much better representation is that shown in figure 5, where the graph is rotated with respect to the page by 45º.

Figure 5 renders it indeed optimally possible to judge equality of the observers' results. Of course, publishers are likely to find this representation less acceptable, and art

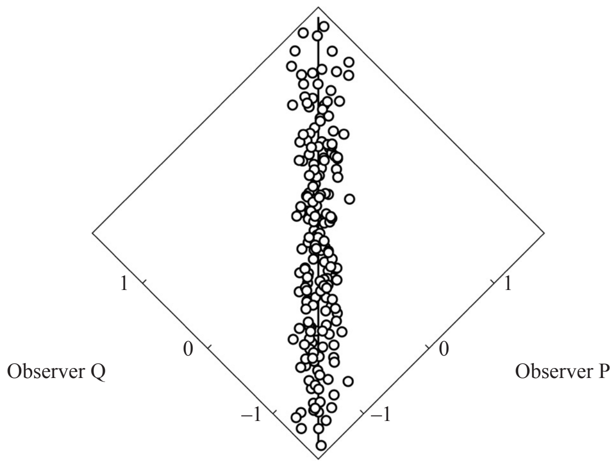

Figure 5. Again, we have the same data as shown in figure 1. In this plot the orientation has been changed by 45º (counterclockwise); otherwise this graph is identical to the previous one. Are the observers (statistically) equivalent? Here the judgment depends upon the perception of bilateral symmetry about the vertical. Since Mach's seminal publication, we know that this is something the human visual system is tuned for. It reflects the symmetries of our bodies and brains. This is what we look for in potential sexual mates—the perceptual habit is deeply ingrained. Notice that you now need to decide on the lettering of the axes—I show merely one possible solution here.

directors (or page designers) might consider it ugly. However, from the perspective of optimal scientific communication, this version is doubtless much better than the previous ones. There is plenty of evidence from perception research to corroborate this statement.

As a minor aside, the rotation of the graph by 45º is formally identical to plotting the pairwise differences against the pairwise means.[1] This is shown in figure 6. The equality is just as conveniently judged in figure 6 left as it is in figure 5. It is the same judgment of (statistical) bilateral symmetry about the vertical.

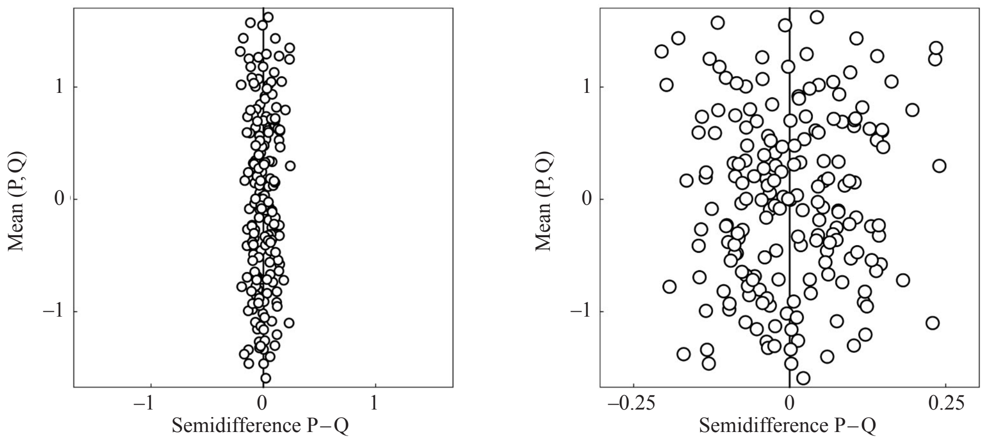

Figure 6. Again, we have the same data as shown in figure 1. Purely visually, this is the same plot as the previous one (really!). The only difference is in the coordinate frame. But from an intuitive perspective this is a very different representation: the pairwise semidifferences have been plotted against the pairwise means. It has the added advantage that you may now scale the axes unequally—this still treats both datasets equally. It uses the white space much more efficiently, and renders the perceptual judgment of statistical bilateral symmetry much more precise.

However, in this case the rendering can be much improved (figure 6 right). Yet, somehow, the representation in figures 6 left and (especially!) right appears *contrived*. It looks like the invention of some smart-ass statistician, instead of appearing as the honest, immediate representation of empirical data. After all, one of the major appeals of scatterplots is exactly that. Apparently, we run into a cognitive bottleneck here. This is yet another irrelevancy to the hardcore scientist, but important to people like me.

Figures 1 through 6 all show *exactly the same data*. Many people—especially those of us with a stronger linguistic than visual 'interface'—will consider them trivially equivalent! No doubt they are. Yet the science of perception tells us that the majority of plot readers will 'get the message' much more effectively from figure 5 than from any of the others. Figure 6 right may be an exception, but then it somehow seems a cheat. *What makes all the difference is the issue of visual perception*.

[1] It is sufficient to notice that the transformation

$$u = x \cos(45^\circ) - y \sin(45^\circ)\,,$$
$$v = x \sin(45^\circ) + y \cos(45^\circ)\,,$$

which expresses the coordinates $\{u, v\}$ in the rotated figure in terms of the coordinates $\{x, y\}$ of the original image, is formally identical to

$$u = (x-y)/2^{1/2}\,,$$
$$v = (x+y)/2^{1/2}\,.$$

[This is the case because cos(45º) and sin(45º) happen to coincide numerically, both equal $1/2^{1/2}$.] As a result, v equals the pairwise mean of x and y multiplied by a constant ($2^{1/2}$), and u the pairwise semidifference of x and y multiplied by the same constant.

Are *we*—perceptual scientists—'users' of our own products? Perhaps surprising—at least to me—is that the answer is not an unconditional *yes*. Apparently the baker doesn't eat his own bread, whereas we should be power users! Why? No idea. But perhaps we should reflect a bit when we are once more irritated by a horrible user interface—not recognizing elementary symmetry principles (Cairns and Thimbleby 2008) such as industry presents to us on a daily basis.

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